Robotic Tunneling Worm for Operation in Harsh Environments

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Introduction

Our team has ***conceptualized*** and ***initiated prototyping*** of a burrowing robotic worm. One key function of this robot is to retrieve lunar samples taken from various depths within the lunar regolith, for either in-situ analysis or for return to Earth. These samples offer a wealth of information on the Moon's impact history and evolution.

Tapping into the lunar regolith requires a unique approach. Regolith is abrasive, becomes denser with increasing depth, is magnetic, readily sticks to surfaces (via electrostatic force), and contains all size materials from the sub-micron to large boulders [1,2].

Concept Design Overview

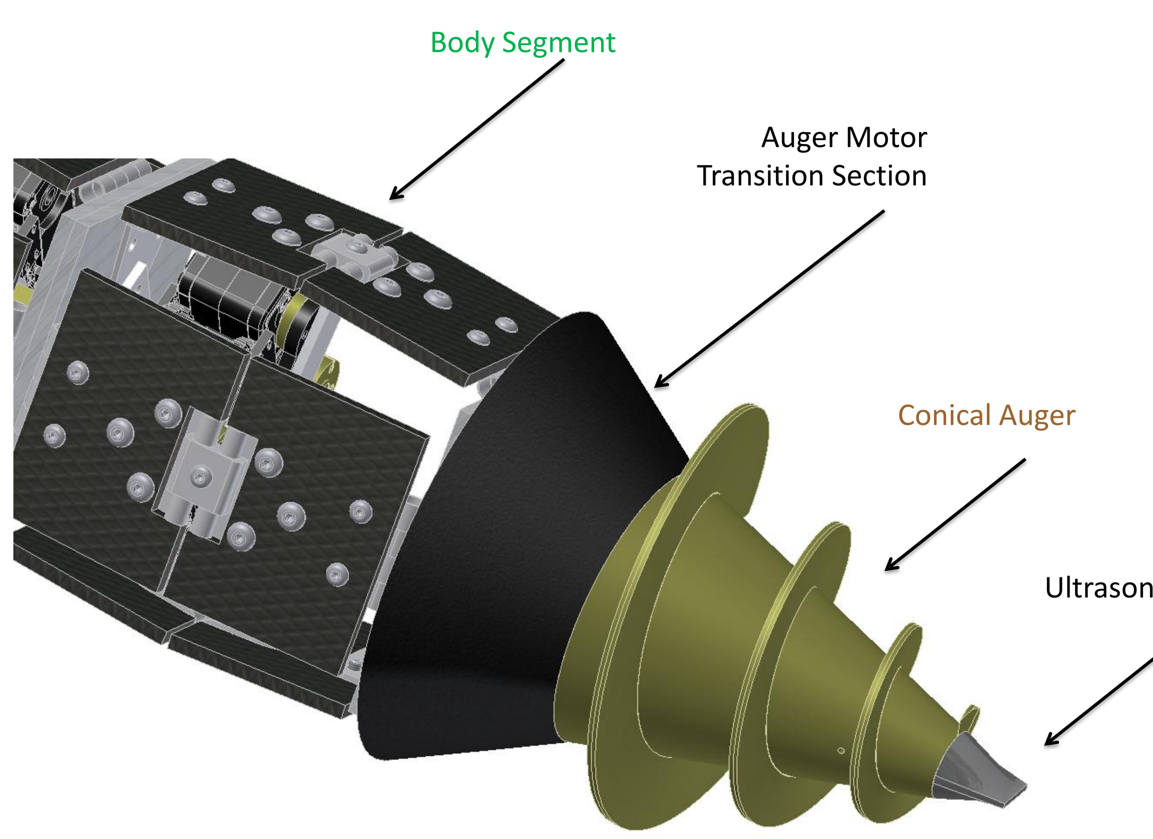

Figure 1. Close up of front end of the robot. Dust shroud not shown for clarity.

The robotic worm design consists of a piezoelectric ultrasonic drill, a conical auger, and multiple elongating segments mimicking the peristaltic motion of an earthworm. We combined these three independent drilling techniques proposed in [3,4,5] into a single platform so that the capabilities of each subsystem complement each other in the drilling process (Fig. 2).

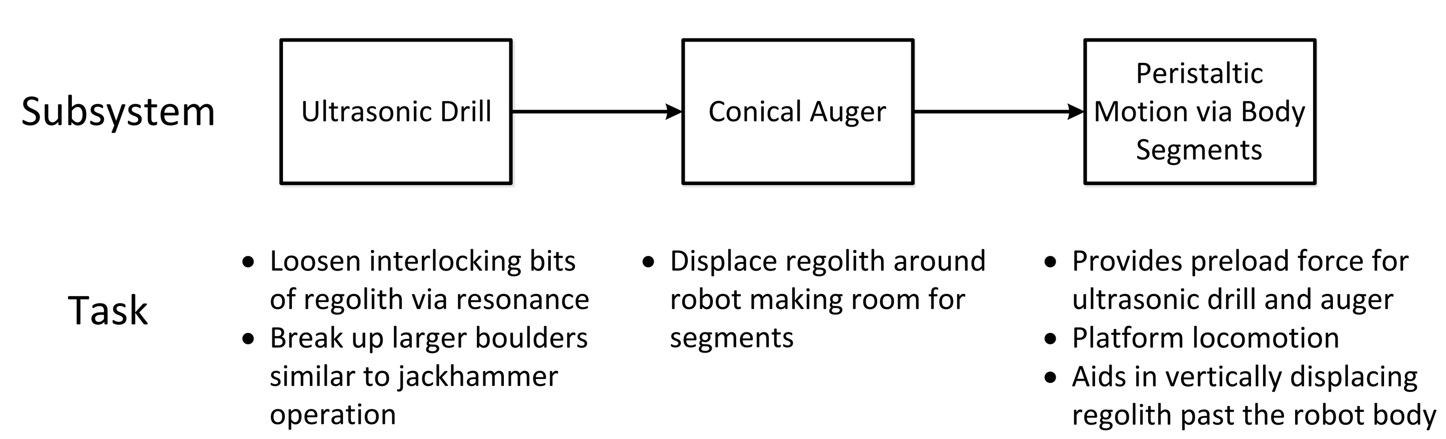

Figure 2. Brief overview of subsystem interactions

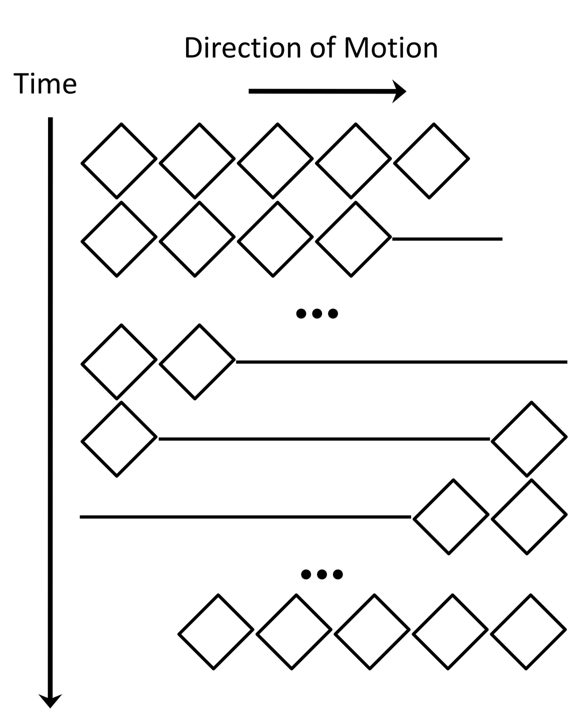

Figure 3. Abbreviated worm segment control sequence demonstrating peristaltic motion.

Peristaltic Motion

•Actuators within the segments contract or expand in the sequence shown in Fig. 3 to mimic peristaltic motion.

•This design forces the platform to travel along a single direction of motion.

•Multiple actuators per segment will allow the next wormlike robot version to turn.

Figure 4. Conceptual design of lunar wormlike robot.

Experimental Prototype and Testing

We have designed and built a single segment and auger (without the ultrasonic drill), to determine the feasibility of the design given the required actuation capabilities (i.e. stroke length) and forces generated required for burrowing. We have also developed the necessary testing apparatuses and experiments to obtain performance parameters.

Worm Segment

• 4 Dynamixel AX-12+ servos use pistons to apply force directly to individual side plate hinges.

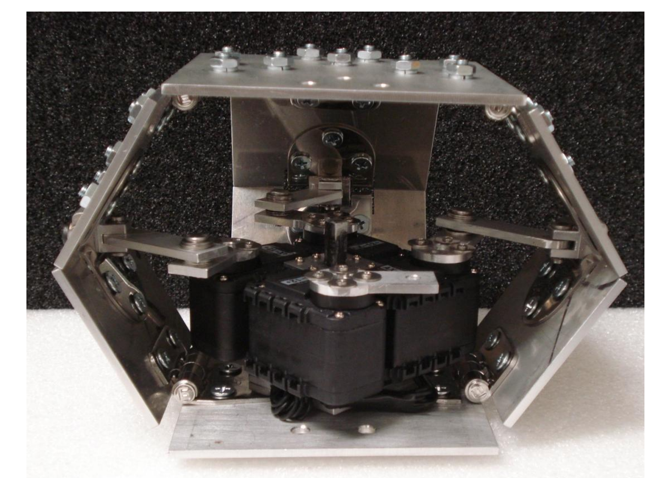

Figure 5. Prototype worm segment, side plate removed to show internals.

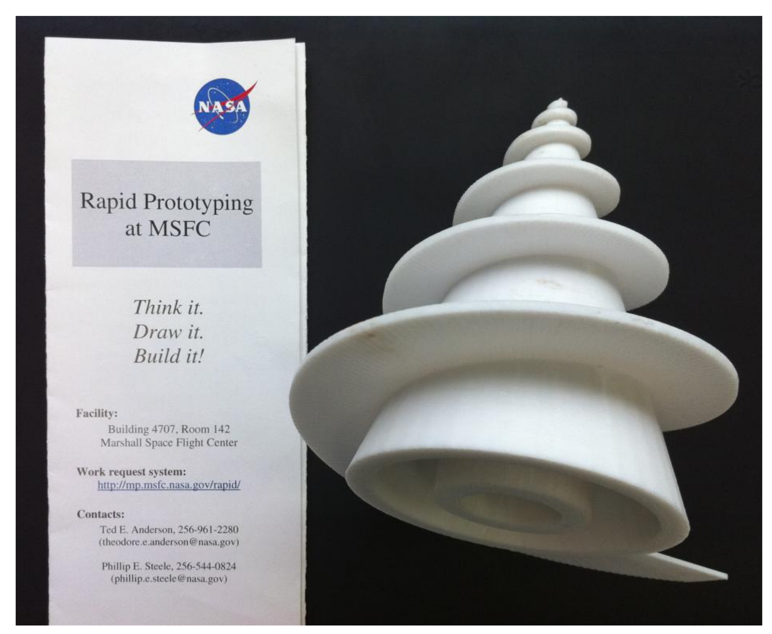

Figure 6. Prototype Conical Auger.

Auger Section

• Adapted from designs found in JAXA paper on tunneling robot research [5].

• Created using fused deposition modeling rapid prototyping (at MSFC).

• Powered by a brushless DC motor with a planetary gearbox.

Control System

• Arduino Mega microcontroller controls the prototype.

• PC records data via USB.

• AX-12+ servos are controlled synchronously over a half-duplex serial bus.

• Motor controller is autonomously controlled by the Arduino.

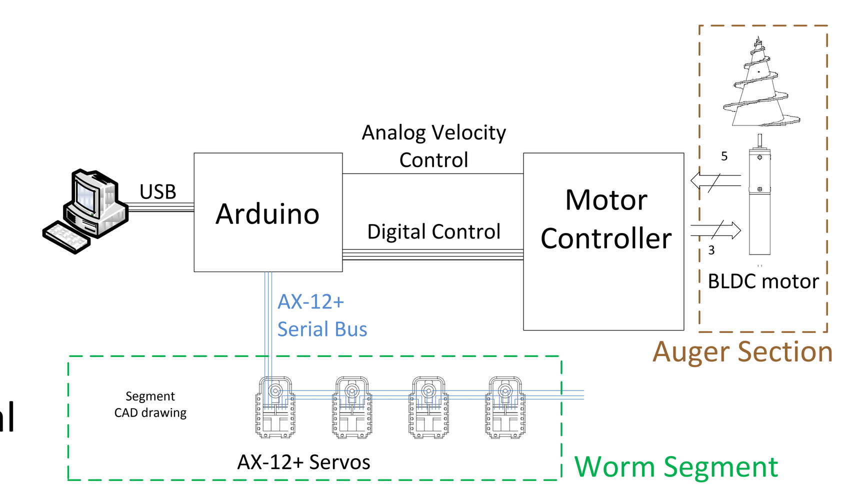

Figure 7. Diagram of robot control system

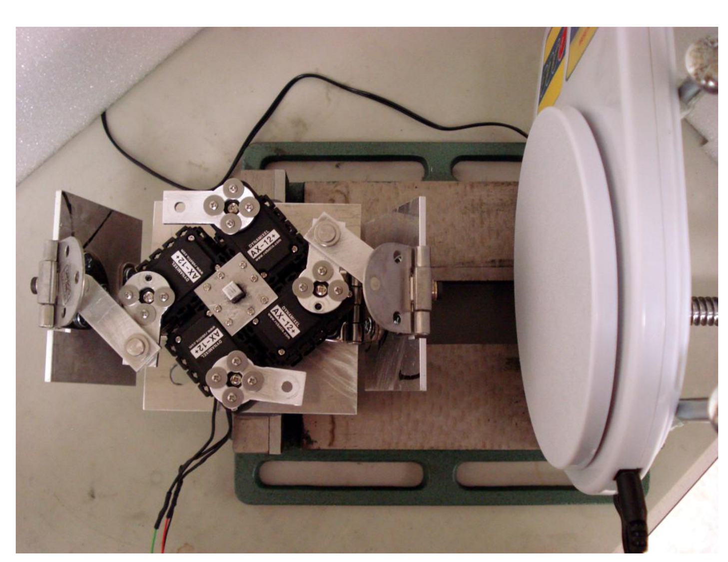

Figure 8. Segment with top plate removed on segment test apparatus

Segment Testing

• Simulates robot exerting force on tunnel walls to maintain position.

• Tests force output characteristics of actuator design in segment.

• Utilizes drill press vise and electronic balance to measure forces generated at different stroke lengths and to measure the load during static testing.

Auger Testing

• Uses flour as lunar regolith analog.

• Test chamber is 3' in diameter (over 6x the auger diameter) to represent applied forces.

• Controlled drilling (preload force and rotational speed) to measure auger performance.

• Will compute specific energy as a performance metric [6].

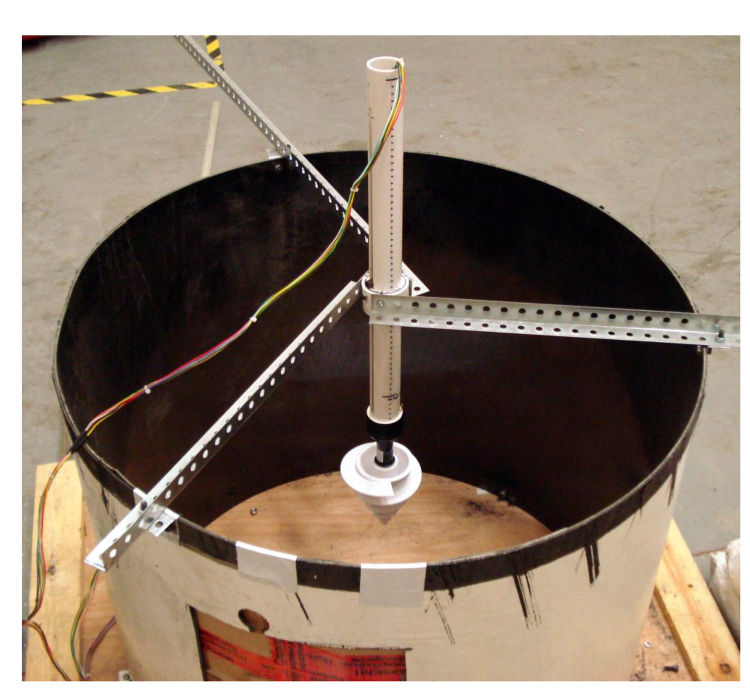

Figure 9. Auger test bed (before adding flour).

Preliminary Results

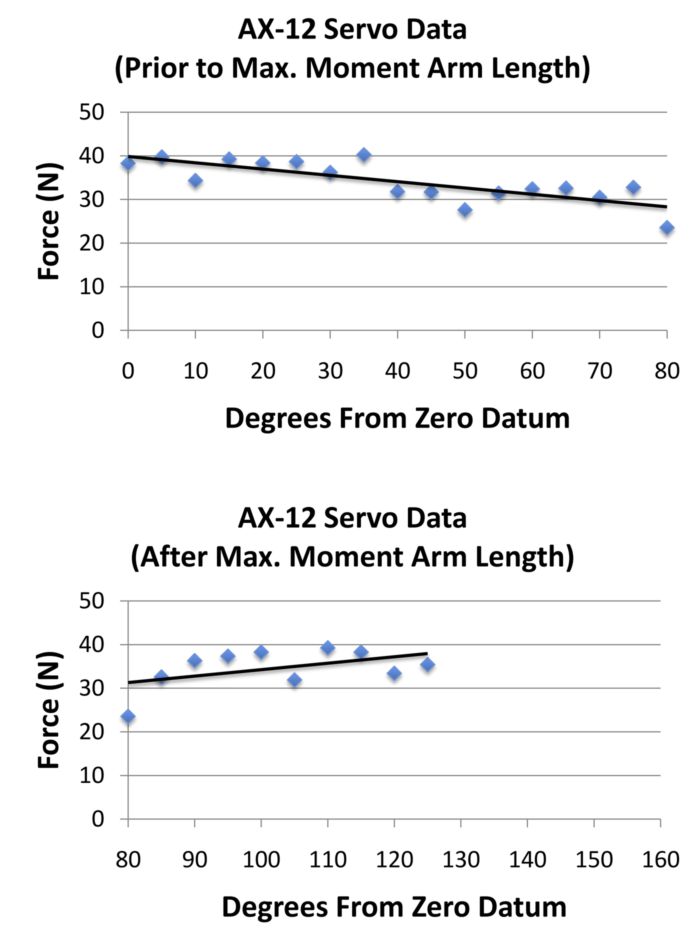

Figure 10. Force output characteristics of a single servo given piston angle during static testing.

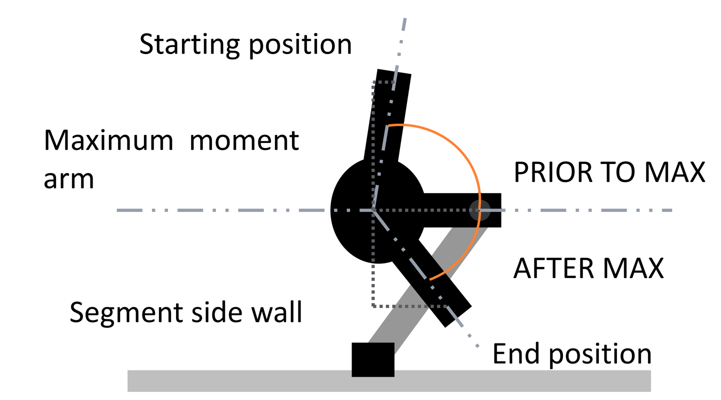

Figure 11. Diagram highlighting moment arm geometry clarifying AX-12 servo data.

Servo testing estimated the maximum static force the prototype exerts on the tunnel walls to maintain position. While horizontal actuation at the hinge design has the advantage of 100% power transmission from servo torque, we did have to contest with varying linear force output at the segment wall.

This varying output is due to the increasing and decreasing moment arm length as the servo horn rotates. We will extrapolate the servo test data to model multiple segments and compare it to the measured forces required to drill with the auger. We will also compare the specific energy specifications of our conical auger design to JAXA's burrowing robot design outlined in [5].

Future Work

We have outlined various continuing projects that directly pertain to the design and construction of a flight-ready wormlike robot. Some of these will be used for Senior Design projects at UAH (led by Dr. C. Carmen).

Ultrasonic Drilling

JPL's Advanced Technology Group has developed and tested a space flight worthy ultrasonic drill capable of efficiently cutting through basalts [3]. The drill is highly configurable and can accommodate many part geometries, from the horn to the drill stem, making the design very flexible for different environments. The desire is for future wormbots to include this existing technology.

Auger Redesign

•Material Selection

•Driven off axis to include ultrasonic drill

•Design connection so that regolith doesn't jam auger

Worm Segment Actuator

The AX-12+ servos chosen for the prototype need to be replaced with more compact and efficient actuators for space flight.

Acknowledgements

The authors would like to thank Dr. Jessica Gaskin, Mr. Richard Cloyd, Mr. Mark Sloan, Dr. Khalid Alshibli, Mr. Ted Anderson, Mr. Phillip Steele, Dr. Babara Cohen, Dr. Jennifer Edmundson, Ms. Tia Ferguson, Dr. Christina Carmen, and Mr. Benjamin DiMiero for their technical advice and assistance, the MSFC Robotics Academy, the Alabama Space Grant Consortium, the Florida Space Grant Consortium, the Maryland Space Grant Consortium, and the New York Space Grant Consortium.

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